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On the interpretation of the apparent existence of a preferred magnetic polarity in extragalactic jet sources

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ABSTRACT

Contopoulos et al. recently argued that there is observational evidence for a preferred sense of the Faraday rotation-measure gradients across jets from active galactic nuclei (AGNs). Such behaviour could arise if there were a deterministic relationship between the polarity of the poloidal magnetic field that threads the outflow and the sense of rotation of the outflow's source. Based on this interpretation, Countopoulos et al. suggested that their finding supports a model for the origin of cosmic magnetic fields in a Poynting-Robertson process operating in AGN accretion discs. Here I point out that an alternative explanation of such a relationship could be that the Hall current plays a key role in the magnetohydrodynamics of the underlying disc. In this picture, the measured Faraday rotation is dominated by the contribution of a centrifugally driven wind that is launched from the weakly ionized outer region of the disc. Additional observations are, however, needed to verify the claimed behaviour.

Key words: accretion, accretion discs – galaxies: active – glalaxies: jets – galaxies: magnetic fields.

1 INTRODUCTION

In a recent paper, Contopoulos et al. (2009, hereafter CCKG09) compiled data on transverse gradients in the Faraday rotation measure (FRM) across jets associated with active galactic nuclei (AGNs). The data were obtained by high-resolution (milliarcseconds, typically corresponding to a projected scale of parsecs at the source) multi-wavelength radio polarization observations. They found that the majority (22/29) of sources in which gradients were detected relatively close to the base of the jet exhibited clockwise gradients. As explained by CCKG09, such gradients are expected in outflows that contain a helical magnetic field (see Fig. 1 in Gabuzda 2008). A helical field arises naturally when poloidal field lines that thread the outflow are twisted by the differential rotation of the source (an accretion disc or the central black hole in the case of AGNs), and the sense of the twist (as reflected in the FRM gradient) is directly related to the relative orientation of the poloidal field and the rotation vector (see Fig. 2 in Gabuzda et al. 2008). The inferred ordered magnetic field could originate in stars or interstellar gas and be dragged into the jet launching region by the accretion flow, or it could be generated in the disc by a dynamo mechanism. In either case, one would expect an equal probability for the poloidal field component to have positive or negative polarity. (For definiteness, I take the source to be a disc whose rotation vector points along the $+\hat{\boldsymbol{z}}$ direction of a cylindrical coordinate system $\{r, \phi, z\}$ placed at the disc's centre, with the polarity of the magnetic field $\boldsymbol{B}$ defined as $\mathrm{sgn}\{B_z\}$.) CCKG09 suggested that the low ($< 1\%$) probability for the compiled distribution to be a chance occurrence indicates that there is a physical mechanism that acts to impose a *positive* magnetic polarity (i.e. B_z parallel to the rotation vector) at the source of AGN jets.

CCKG09 proposed that the relevant mechanism is the Poynting-Robertson 'Cosmic Battery' effect (Contopoulos & Kazanas 1998). In this picture, the radiation drag induced by the central AGN radiation field and acting predominantly on the electrons in a rotating circumnuclear disc gives rise to an azimuthal current that generates a poloidal magnetic field with a unique (positive) polarity. Although the viability of this mechanism has been debated in the literature (e.g. Bisnovatyi-Kogan & Blinnikov 1977; Bisnovatyi-Kogan, Lovelace & Belinski 2002; Contopoulos, Kazanas & Christodoulou 2006; Christodoulou, Contopoulos & Kazanas 2008), CCKG09 argued that the indicated preponderance of positive polarities in AGN jets could be an important factor in its favour in view of the apparent difficulty of explaining this behaviour 'using any standard MHD model in the literature'. Here I point out that, in fact, a single- (positive) polarity disc outflow can naturally form also under 'standard MHD' conditions if the Hall current af-

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fects the magnetohydrodynamics (MHD) of the associated accretion flow. In this picture, the gas that dominates the observed FRMs corresponds to a wind that originates in the comparatively massive and weakly ionized outer region of the disc. If the claimed effect is real (which, in view of the considerable observational difficulties involved, requires further confirmation) and the disc-wind interpretation is correct then the FRM measurements could yield valuable clues to the physical conditions in the outflow as well as in the underlying disc.

2 HALL-CURRENT EFFECTS IN WIND-DRIVING DISCS

For the purpose of illustration, I consider a simplified model of a wind-driving Newtonian disc that is in nearly Keplerian rotation (with azimuthal speed $|v_\phi| \approx v_{\rm K}$) around a black hole of mass M, vertically isothermal (with sound speed $c_{\rm s}$) and geometrically thin (so that the density scaleheight $h(r) \ll r$). I focus on systems that are axisymmetric and in a steady state on the dynamical time $\Omega_{\rm K}^{-1}(r) = r/v_{\rm K}(r)$. I consider outflows that are launched in the form of a centrifugally driven wind (e.g. Blandford & Payne 1982), which are also relevant to jets that attain relativistic speeds (e.g. Vlahakis & Königl 2004). The disc is assumed to be threaded by a large-scale, open magnetic field with an 'even' B_z symmetry about the mid-plane (corresponding to $B_r = B_\phi = 0$ at $z = 0$). On going away from the mid-plane, the poloidal field lines bend away from the rotation axis, and the resulting radial component (B_r) is sheared by the disc's differential rotation to produce an azimuthal component (B_ϕ). The radial and azimuthal field components generated in this way satisfy $B_r B_\phi < 0$. The B_ϕ component induces a torque ($\propto r B_z B_\phi$) that acts to brake the disc rotation. The magnetic field removes angular momentum from the disc, and, if the field-line inclination at the disc's surface is large enough ($B_r/B_z > 1/\sqrt{3}$), a wind can be launched wherein the field transfers the angular momentum back to the gas (thereby accelerating it 'centrifugally').

The azimuthal shearing as well as the tendency of the accretion flow to advect the magnetic field lines inward are countered by the magnetic diffusivity of the gas. However, the diffusivity cannot be too large if vertical magnetic transport of angular momentum is to take place; in fact, the minimum-coupling condition is essentially the same as the corresponding condition for efficient radial magnetic transport through turbulence induced by the magnetorotational instability (MRI; see Königl & Salmeron 2011). In the region where this condition is satisfied, MRI may dominate at low disc elevations, with vertical transport by the large-scale field taking over further up (Salmeron et al. 2007, hereafter SKW07). However, to simplify the discussion, I assume that the degree of coupling and the magnetic field strength are high enough for vertical transport to dominate already at the mid-plane. Wind-driving disc models of this type were previously studied in the context of protostellar systems (e.g. Wardle & Königl 1993; Königl, Salmeron & Wardle 2010; Salmeron, Königl & Wardle 2010; hereafter WK93, KSW10 and SKW10, respectively).

The vertical structure of the envisioned wind-driving disc region is shown schematically in Fig. 1. One can identify three basic zones (WK93): the quasi-hydrostatic layer near the mid-plane (between $z = 0$ and $z_{\rm h} = h$) where the bulk of the matter is concentrated and most of the field-line bending takes place, a transition zone where the magnetic pressure comes to dominate the thermal pressure and the inflow gradually diminishes, and an outflow region (between the top of the disc at $z_{\rm b}$ and the 'sonic' critical surface at $z_{\rm s}$) that corresponds to the base of the wind (with the mass outflow rate effectively determined by imposing the regularity condition at $z_{\rm s}$). The magnetic field lines are tied (possibly imperfectly) to the ionized disc component, and the collisional drag between this component and the neutrals transmits the magnetic torque to the bulk of the gas. Therefore $v_{{\rm B}\phi} < v_\phi$ inside the disc. The loss of angular momentum enables the neutrals to drift toward the centre, resulting in a radial drag on the ionized component that tends to impart an inward radial speed $|v_{{\rm B}r}| < |v_r|$ to the field lines. The radial drag is balanced by the magnetic tension exerted by the outward-bent field lines, and this force, in turn, contributes to the radial support of the neutral gas inside the disc and causes it to rotate at sub-Keplerian speeds ($v_\phi < v_{\rm K}$). Outside the disc the situation is reversed: the field lines transfer angular momentum to the matter ($v_{{\rm B}\phi} > v_\phi$), which consequently rotates at super-Keplerian speeds ($v_\phi > v_{\rm K}$).

The effect of the magnetic tension on the disc gas can be seen explicitly from the r component of the momentum equation, which in the quasi-hydrostatic region of a thin disc (in which the v_z velocity component can be neglected and vertical gradients almost always dominate radial gradients) can be approximated by

$$\frac{2\rho v_{\rm K}}{r}(v_{\rm K} - v_\phi) \approx \frac{J_\phi B_z}{c} \tag{1}$$

(KSW10), where ρ is the mass density, c is the speed of light and the term involving the current density $J_\phi \approx (c/4\pi)\partial B_r/\partial z$ represents the magnetic tension force. Under the same approximations, and assuming that angular momentum transport by the large-scale field dominates, the ϕ component of the momentum equation can be written as

$$\frac{\rho v_r v_{\rm K}}{2r} \approx -\frac{J_r B_z}{c}\ , \tag{2}$$

where $J_r \approx -(c/4\pi)\partial B_\phi/\partial z$. Combining equations (1) and (2) yields

$$\left(\frac{dB_r}{dB_\phi}\right)_0 = \frac{4(v_{\rm K} - v_{\phi 0})}{v_{r0}} < 0 \tag{3}$$

(where the subscript '0' denotes the mid-plane), which corroborates the inference that $B_r B_\phi < 0$ in the wind-driving region of the disc.

The effect of the magnetic diffusivity on the disc structure can be inferred from a consideration of Ohm's law, which for a weakly ionized gas takes the form

$$\boldsymbol{E} = -\frac{\boldsymbol{v}\times\boldsymbol{B}}{c} + \frac{4\pi}{c^2}\left[\eta_{\rm O}\boldsymbol{J} + \eta_{\rm H}\frac{\boldsymbol{J}\times\boldsymbol{B}}{B} - \eta_{\rm A}\frac{(\boldsymbol{J}\times\boldsymbol{B})\times\boldsymbol{B}}{B^2}\right]\ , \tag{4}$$

where $\eta_{\rm O}$, $\eta_{\rm H}$ and $\eta_{\rm A}$ are, respectively, the Ohm, Hall, and ambipolar diffusivities. The latter can be evaluated for an arbitrary charge composition, but it is often a good approximation to assume that the current carriers consist only of electrons (subscript 'e') and singly charged ions (subscript 'i') with a mass ratio $m_{\rm e}/m_{\rm i} \ll 1$. In this case one can write

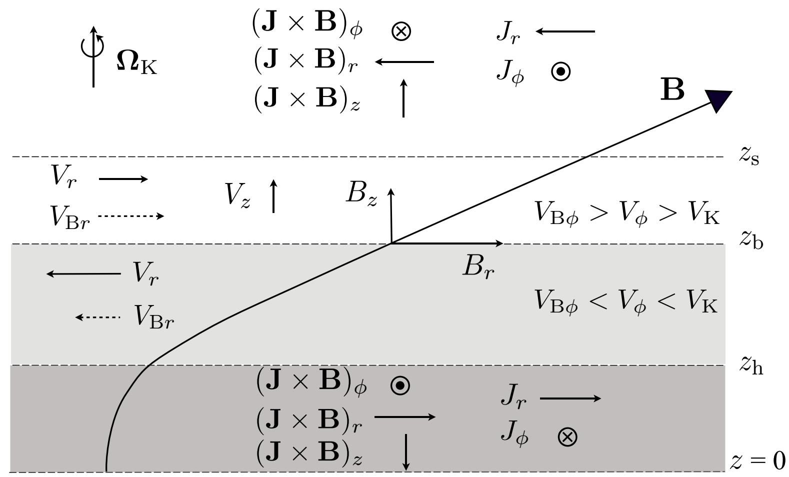

Figure 1. Schematic of the vertical structure of a wind-driving disc, showing a representative field line and the orientations of the Keplerian angular velocity $\mathbf{\Omega}_K$ and of components of the gas velocity ($\mathbf{v}$), field-line velocity ($\mathbf{v}_B$), magnetic field ($\mathbf{B}$), current density ($\mathbf{J} \propto \nabla\times\mathbf{B}$) and magnetic force ($\propto \mathbf{J}\times\mathbf{B}$) vectors in the disc ($z < z_b$) and wind ($z > z_b$) regions. See text for further details.

$\eta_O = c^2/4\pi\sigma_e$, $\eta_H = \beta_e\eta_O$ and $\eta_A = \beta_e\beta_i\eta_O$ (Wardle 2007), where $\sigma_e = n_e e^2/m_e\nu_e$ is the electron conductivity and

$$\beta_j \equiv \frac{eB}{m_j c}\frac{1}{\nu_j} \tag{5}$$

is the Hall parameter of a charged species j. In these expressions, n_e is the electron number density (which is equal to n_i), e is the electronic charge, $\nu_j = \rho <\sigma v>_{jn}/(m_j+m_n)$ is the momentum-exchange collision frequency with the neutral (subscript 'n') particles (where $<\sigma v>_{jn}$ is the charge–neutral momentum transfer rate) and $B \equiv |\mathbf{B}|\,\mathrm{sgn}\{B_z\}$ is the *signed* magnetic field amplitude. The absolute value of β_j represents the ratio of the cyclotron frequency ω_{cj} to ν_j and is a measure of whether the corresponding charged particle is well ($|\beta_j| \gg 1$) or poorly ($|\beta_j| \ll 1$) coupled to the magnetic field. Using $m_i \approx 30\, m_H$ (e.g. Draine, Roberge & Dalgarno 1983), the ratio of the ion and electron Hall parameters can be estimated to be $q \equiv \beta_i/\beta_e \approx 1.3\times10^{-4}\sqrt{T}$ (where T is the gas temperature), which is typically $\ll 1$.

Note that, among the three diffusivity terms, only η_H depends on an odd power of B – this is the origin of the dependence of the disc solutions on the magnetic field polarity when the Hall current is dynamically important. To demonstrate the fact that negative-polarity field configurations are excluded in certain parameter regimes, consider the ϕ component of equation (4) in the quasi-hydrostatic zone. As discussed in KSW10, $E_\phi \approx E_{\phi0} = v_{Br0}B_z/c$ can be set equal to zero in this analysis without loss of generality (see their Appendix A, where it is also argued that physical consistency requires one to consider all the terms in Ohm's law even in the nominally Hall-dominated regime). The advective term is approximately $v_r B_z/c$, where v_r can be expressed in terms of J_r using equation (2). Evaluating at $z = 0$, one gets

$$\left(\frac{dB_r}{dB_\phi}\right)_0 = -\frac{J_{\phi0}}{J_{r0}} = -\frac{2a_0^2+\tilde{\eta}_{H0}}{\tilde{\eta}_{O0}+\tilde{\eta}_{A0}} = -\frac{2\Upsilon_0+\beta_{i0}^{-1}}{1+\beta_{e0}^{-1}\beta_{i0}^{-1}}\,, \tag{6}$$

where the third expression is general and the fourth one applies in the case of a two-component plasma with $q \ll 1$. In equation (6), the diffusivities are normalized using $\tilde{\eta} \equiv \eta/h_T c_s$, where $h_T = c_s^2/\Omega_K$ is the tidal scaleheight, and the parameters

$$a_0 \equiv \frac{v_{A0}}{c_s}\,, \tag{7}$$

the mid-plane ratio of the Alfvén speed $v_A = |\mathbf{B}|/\sqrt{4\pi\rho}$ to the isothermal sound speed, and

$$\Upsilon_0 \equiv \frac{\nu_{i0}}{\Omega_K}\frac{m_i n_{i0}}{\rho_0}\,, \tag{8}$$

the mid-plane ratio of the Keplerian rotation time to the neutral–ion momentum exchange time, are generally $\lesssim 1$ and $\gtrsim 1$, respectively (see KSW10). The two terms in the numerator of the third (or fourth) expression in equation (6) arise, respectively, from advective and Hall terms in Ohm's law. Their ratio is given by

$$\frac{\text{Hall}}{\text{advective}} = \frac{|\tilde{\eta}_{H0}|}{2a_0^2} = \frac{1}{2\Upsilon_0|\beta_{i0}|} = \frac{\Omega_K}{2\omega_{H0}}\,, \tag{9}$$

where the last expression involves the Hall frequency

$$\omega_H \equiv \frac{n_i}{\mu n}\,\omega_{cp}\,, \tag{10}$$

whose inverse represents the characteristic time-scale of the Hall effect in MHD (e.g. Pandey & Wardle 2008). (Here n is the particle number density, μ the molecular weight and the subscript p denotes a proton.) When the ratio (9) is > 1 and $\mathrm{sgn}\{B_z\} < 0$, equation (6) implies that $(dB_r/dB_\phi)_0$ is > 0, which is inconsistent with the inference from the physical model (equation 3). Therefore, when this ratio is > 1, *only positive-polarity disc outflows can form.*

Specializing to the case of a two-component plasma with $q \ll 1$, the Hall-dominance condition can be written as

$$\frac{\Omega_K}{2\omega_{H0}} = \frac{\mu_d}{2}\frac{\Omega_K}{\omega_{cp0}}\frac{1}{x_{id0}} = \frac{8.2\times10^{-13}}{x_{id0}}\frac{M_8^{1/2}}{B_{0.1}r_{0.1}^{3/2}} > 1\,, \tag{11}$$

where the subscript 'd' denotes the disc, $x_{id} \equiv n_{id}/n_d$ is the degree of ionization of the disc gas, $\mu_d \approx 2.33$, $M_8 \equiv M/10^8\,M_\odot$, $B_{0.1} \equiv B_0/0.1\,\mathrm{G}$ and $r_{0.1} \equiv r/0.1\,\mathrm{pc}$. When the parameter constraints on physically viable wind-driving molecular discs are analyzed in detail (see WK93, KSW10 and SKW10), one finds that the condition (11) is satisfied in two (out of the four identified) parameter regimes

in the nominal Hall diffusivity domain ($|\beta_{\rm i}| \ll 1 \ll |\beta_{\rm e}|$) and in one regime (out of the three identified) in the nominal Ohm domain ($|\beta_{\rm e}| \ll 1$). These are precisely the parameter regimes that admit only positive-polarity disc/wind solutions. (In the other viable-solution regimes both polarities are allowed.) In what follows, I consider whether the inequality (11) can be satisfied in AGN discs but do not address the additional parameter constraints derived in the above-cited references, which could, however, be useful in a more detailed treatment.

3 APPLICATION TO AGN DISCS

Although the physical variables that appear in equation (11) cannot be directly determined from existing observations, one can nevertheless extract useful clues from the Faraday rotation measurements themselves. For example, Kharb et al. (2009) deduced from observations of parsec-scale jets in Fanaroff-Riley Type I (FR I) radio galaxies that the Faraday rotation is likely associated with a helical (or toroidal) magnetic field and that it arises in a 'sheath' around the jet, which could correspond to a magnetized disc wind (e.g. Blandford & Levinson 1995). They inferred the magnetic field amplitude by equating it to the equipartition field ($\sim 5\,$mG) derived from the synchrotron radio emission in the jet, which is reasonable if the jet is confined by the disc wind and both represent MHD outflows that are magnetic pressure dominated. Using a representative FRM value of 200 rad m^{-2} and a pathlength of $\sim$ 1 pc through the sheath, they estimated a characteristic electron density of ~ 0.03 cm^{-3}. This value could plausibly be ascribed to the atomic hydrogen layer that arises in the innermost zone of a photodissociation region formed when the AGN ionizing radiation (assumed not to be dominated by hard X-rays) impinges on the disc outflow (e.g. Tielens & Hollenbach 1985). A layer of this type is established just beyond the HII/HI transition zone (whose column density is $\lesssim 10^{20}\,{\rm cm}^{-2}$) and has a characteristic electron fraction of $\sim 3\times10^{-4}$ (resulting primarily from singly ionized carbon atoms). This, in turn, implies a density $n_{\rm w} \approx 10^2\,{\rm cm}^{-3}$ (where the subscript 'w' denotes the wind) within the sheath.

Now, if the parsec-scale sheath with $|B| \lesssim 10\,$mG can be identified with a centrifugally driven disc wind, the outflow likely originates on scales $r \lesssim 0.1\,$pc, where the magnetic field strength is $B(r) \lesssim 0.1\,$G, and its speed $v_{\rm w}$ is $\gtrsim v_{\rm K}(r)$ (e.g. Blandford & Payne 1982). I adopt $r_{0.1} = 1$ and $B_{0.1} = 1$ as fiducial values and use $M_8 = 3$ as a representative mass for radio-loud AGNs (e.g. Sikora, Stawarz & Lasota 2007). The mass outflow rate in the sheath can be estimated to be $\sim r_{\rm w}^2 \mu_{\rm w} m_{\rm p} n_{\rm w} v_{\rm w} \approx 8\times10^{23}\,{\rm g\,s^{-1}}$ (using $r_{\rm w} \approx 1\,$pc, $v_{\rm w} \approx v_{\rm K}(r_{0.1}=1)$ and $\mu_{\rm w} \approx 1.27$). Given that an efficient disc wind typically has a mass outflow rate that is about an order of magnitude smaller than the accretion rate (e.g. Königl & Salmeron 2011), I adopt $\dot M_{25} \equiv \dot M/10^{25}\,{\rm g\,s^{-1}} \approx 1$ (corresponding to $\dot M \approx 0.16\,{\rm M_\odot\,yr^{-1}}$) for the mass accretion rate at $r_{0.1} = 1$. The mid-plane-to-disc-surface column density is given by $N = \dot M/4\pi r \mu_{\rm d} m_{\rm p}|v_{r0}|$, and, by setting $h \approx h_{\rm T}$ (an upper limit due to the magnetic squeezing of the disc; see KSW10 and Fig 1), a lower limit on the mid-plane density can be obtained by writing $n_{\rm d0} = (2/\pi)^{1/2} N/h_{\rm T}$. Using $|v_{r0}| = 0.1\,\epsilon_{0.1}\,c_{\rm s}$ (where $\epsilon_{0.1}$ is typically $\gtrsim 1$; e.g. SKW07) and adopting $T_{500} \equiv T_0/500\,{\rm K} \approx 1$ as a rough estimate of the mid-plane temperature at the radius of interest, I get $N \approx 5\times10^{25}\,\dot M_{25}\,\epsilon_{0.1}^{-1}\,r_{0.1}^{-1}\,T_{500}^{-1/2}$ cm^{-2} and $n_{\rm d0} \gtrsim 3\times10^{11}\,(M_8/3)^{1/2}\,\dot M_{25}\,\epsilon_{0.1}^{-1}\,r_{0.1}^{-5/2}\,T_{500}^{-1}$ cm^{-3}.

For the adopted values of M_8, $r_{0.1}$ and $B_{0.1}$, the condition given by equation (11) can be fulfilled if $x_{\rm id0} \lesssim 10^{-12}$. The dominant ionization agent for the inferred values of r and N would likely be cosmic rays, and if one employs the nominal Galactic values for the ionization rate ($\xi_{\rm CR} \approx 1\times10^{-17}\,{\rm s^{-1}}$), the cosmic-ray attenuation grammage ($\chi \approx 100\,{\rm g\,cm^{-2}}$) and the gas-to-dust mass ratio (≈ 100), one finds that the requirement on $x_{\rm id0}$ should be satisfied for the modelled disc (e.g. Umebayashi & Nakano 1990). Although the charged-particle abundances depend on the uncertain heavy-element depletions and grain size distribution, ions and electrons have a significant influence on the magnetic diffusivity under typical Galactic conditions so long as $(n/\xi_{\rm CR})\exp(\mu_{\rm d} m_{\rm p} N/\chi)$ is $\lesssim 10^{29}\,{\rm cm^{-3}\,s}$ (e.g. Kunz & Mouschovias 2010). At higher values of this parameter combination, singly charged (+ and -) grains of equal mass become the dominant current carriers, which results in the Hall conductivity tending to zero (so Hall effects no longer play a significant role). The actual value of $\xi_{\rm CR}$ in AGN discs is still unknown: on the one hand it might be substantially higher than in the Galaxy (e.g. Bayet et al. 2009), but on the other hand a super-Alfvénic disc outflow and the expected magnetic field geometry of the disc/wind system could strongly reduce the cosmic-ray flux reaching the mid-plane (e.g. Wardle 2007). In view of these uncertainties, the estimates employed in the evaluation of the inequality (11) need to be regarded as merely illustrative. These estimates nevertheless indicate that the proposed scenario is not implausible. Note that the wind-launching region is likely to contain magnetic fields of either polarity, both in the case in which the field is advected from a larger distance (for example, if it originates in stars with randomly oriented magnetic moments whose remnants are brought into the launching region in sufficiently rapid succession) and in the case of a local disc dynamo (e.g. Blackman & Brandenburg 2003). Therefore, when the condition (11) is satisfied, a positive-polarity outflow should in general be able to form.

4 DISCUSSION

In the interpretation outlined in this Letter, the Faraday sheath that was inferred to be the likely source of the measured parsec-scale FRM gradients is identified with a centrifugally driven wind that originates in a weakly ionized, molecular region of an AGN accretion disc at a distance $\gtrsim 0.1$ pc from the central black hole. This picture is consistent with the idea that an MHD disc outflow constitutes the 'dusty torus' that underlies AGN unification schemes (Königl & Kartje 1994). The suggestion that the gas in the outer regions of certain AGN discs is mostly molecular and dusty is supported by several observational findings. Although molecular line measurements do not yet resolve these regions, there are already strong indications that dense, rotating molecular gas is concentrated on scales $\gtrsim 10$ pc around the centres of local AGNs (e.g. Hsieh et al. 2008; Hicks et al. 2009), and numerical simulations (e.g. Wada, Papadopoulos & Spaans 2009; Schartmann et al. 2010) indi-

cate that this gas likely forms a thin disc on smaller scales. Flattened distributions of dust have in fact been imaged in sources like NGC 1068 on $\gtrsim 1$ pc scales by infrared observations (e.g. Raban et al. 2009). Direct evidence for dense ($n \gtrsim 10^8$ cm^{-3}) molecular gas shielded from the central continuum by a large dusty column ($N \gtrsim 10^{23}$ cm^{-2}) has been provided in several AGNs (including NGC 1068; Greenhill & Gwinn 1997) by the detection of flattened distributions (imaged on scales $\sim 0.1-1$ pc) of water masers that exhibit Keplerian (or nearly Keplerian) rotation-velocity profiles. The maser emission could arise either in the circumnuclear disc (e.g. Neufeld & Maloney 1995) or in dense clumps within a dusty disc wind (e.g. Kartje, Königl & Elitzur 1999). Although all the above findings pertain to spiral galaxies (Seyferts and LINERs), there is also evidence that molecular gas is present in the centres of nearby radio-loud elliptical galaxies (e.g. Ocaña Flaquer et al. 2010). Higher-resolution and more sensitive future observations, particularly with ALMA, should shed more light on this issue.

A growing body of data indicates that relativistic AGN jets undergo the bulk of their acceleration and collimation on spatial scales not much smaller than ~ 0.1 pc (e.g. Sikora et al. 2005; Junor, Biretta & Livio 1999). Disc outflows could play an important role in these processes because efficient MHD acceleration to relativistic speeds requires lateral confinement over extended spatial scales (e.g. Komissarov et al. 2009) and because the presence of a surrounding disc wind could greatly facilitate the collimation of a relativistic jet, which might otherwise be hard to achieve (e.g. Gracia et al. 2009). It can be expected that the portion of the disc wind that is most effective in confining the jet on scales $\gtrsim 0.1$ pc along the flow is launched from the disc surface at a comparable distance from the centre (see Spruit, Foglizzo & Stehle 1997). This could naturally account for the proposed identification of the Faraday-rotation sheaths of parsec-scale jets with magnetized winds that originate in the associated AGN discs at $r \gtrsim 0.1$ pc.

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